NASA TECHNICAL TRANSLATION NASA TT F-13,961

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Translation of "Predvaritel'nyye rezul'taty
izucheniya lunnogo grunta," Priroda,
No. 12, December 1970, pp. 5-9

(NASA-TT-F-13961) PRELIMINARY RESULTS OF LUNAR SOIL STUDY A.P. Vinogradov (Translation Consultants, Ltd.) Apr. 1972 12 p CSCL 03B

N72-21861 Unclas G3/30 24007

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 APRIL 1972

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PRELIMINARY RESULTS OF LUNAR SOIL STUDY

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ABSTRACT. Preliminary data on the lunar soil core sample brought back by Luna 16 are presented.

I am reporting some preliminary data on the lunar soil brought back by the automatic station Luna 16. The soil sample was obtained in the north-eastern part of Mare Fecunditatis, in a point with coordinates 0°41'S, 56°18'E, approximately 100 km to the westward of Webb Crater. /5*

Mare Fecunditatis shows traces of comparatively mild subsidence. The shores are rimmed by rugged mountains. It is a plain, traversed by low-lying (100-300 m) branched walls. This section has none of the ray systems of the large craters.

The sample is characteristic of a new region of the lunar maria surface approximately 900 km to the eastward of the Apollo 11 landing site. The drill penetrated the loose lunar mantle, the soil, or the regolith, with comparative ease. Regolith, a term proposed at the end of the last century, refers to the loose surface material on a planet, regardless of the conditions under which formed.

The drill, upon reaching the assigned depth, bit into solid rock, or into a large, isolated rock fragment. Further penetration by the drill was no more than 5 mm, and this is confirmed by inspection of the core sample.

The sample, upon delivery to the Receiving Laboratory, underwent radiation, biological, and toxicological monitoring, all of which, as earlier data have shown, was unnecessary. /6

The core of loose lunar soil (regolith) completely filled the drill. Once on the receiving tray it showed no visible layering and appeared to be uniform throughout the drill depth. Some small part of the soil at a face about 35 cm deep was made up of a more coarse-grained material. The core weighed slightly more than 100 grams.

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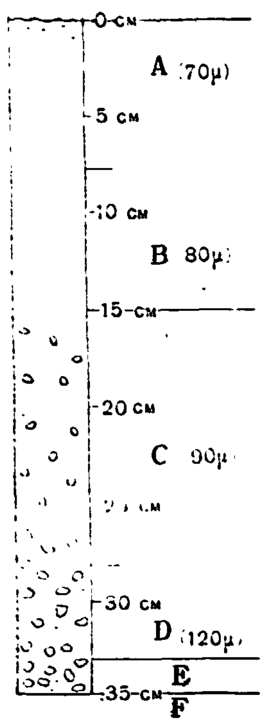
* Numbers in the margin indicate pagination in the foreign text.

Overall view of lunar soil brought back by the automatic station Luna 16.

The soil (regolith) overall is a varigrained dark gray (blackish) powder. It molds readily and coheres into individual, loose lumps. This feature is what makes it distinctly different from structureless earth dust, despite the predominance of fine-grained fractions with an average grain size of about 0.08 to 0.1 mm. In this regard, lunar soil resembles wet sand, or the cloddy structure of our soils. The lunar soil readily takes the impression of all sorts of traces, and the semicircular shaped impressions retained can be seen on the panorama. The soil easily supports even a vertical wall. The soil, poured through a funnel to form a pile 2 cm high near a vertically positioned glass wall, retained its cast without scattering, forming a natural slope with an angle near 45°. It can be sieved easily, despite good cohesion. It is of interest to note that lunar soil is highly susceptible to electrification, something that appears in the manner in which its particles adhere to the surfaces of plexiglass, fluoroplastic, and other materials.



Fine-grained material with few coarse fractions. No rock debris larger than 3 mm.

Varigrained material including rock debris and other particles larger than 3 mm.

Coarse-grained material

Solid rock (or rock fragment)

Lunar soil (regolith) core. A, B, C, D, E - main zones. The average size of fraction particles smaller than 1 mm is shown in parentheses.

Graininess of the soil increases with depth, so in accordance with this criterion, and based on granulom[illegible]tric analysis, it can be broken down into several zones, gradually merging into each other. We shall call these zones A, B, C, D, and E.

Zones A, B - fine-grained material with few coarse fractions - from 0 to 15 cm along the length of the core.

Z[illegible]s C, D - varigrained material with rock debris and other particles larger than [illegible] - from 15 to 33 cm along the length of the core.

Zone E - coarse-grained material - from 33 to 35 cm along the length of the core.

Zone A includes the loosest, the surface, layer (0-5 cm). Its properties determine the principal optical characteristics of the lunar surface and relate to the high porosity of the surface structure. The thickness of the loosest layer apparently varies in different places, but the mean bulk density at 5 cm, according to the Luna 13 data, has been determined to be 0.8 g/cm^3, and this can be taken, tentatively, as the figure for the Luna 16 landing site.

Beneath the core taken on the moon was solid rock, or a rock fragment (the F layer).

The average size of particles smaller than 1 mm varied through the core from 70μ in the surface section to 120μ in the deep section.

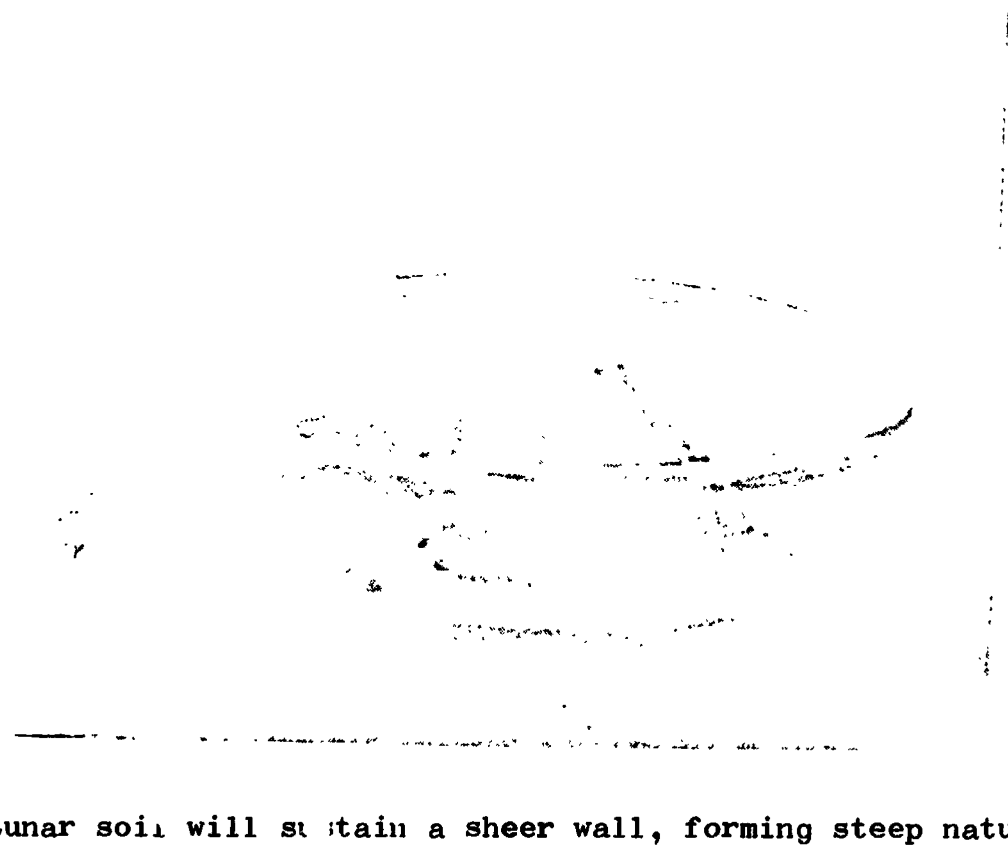
The mean bulk density of the soil in the natural occurrence at the final drill depth was determined to be 1.2 g/cm^3. A bulk density of the same order of magnitude was obtained when the soil was poured freely into a graduate, and 1.8 g/cm^3 was obtained after tamping. The mean porosity of soil on the moon at a depth of 35 cm therefore is determined to be 50-60 percent.

It already has been pointed out that lunar soil is dark gray, or blackish, in color. Visual assessment of its luminosity is extremely difficult because the latter changes greatly with location of light source and observer. This characteristic feature of the lunar soil appears in the unique shape of the scattering curve for different wavelengths and light angles with respect to the soil. The determinant here is the surface structure and the reflecting properties of its component, vitrified grains.

The normal albedo, determined by instrument, varies from 8.6 percent in the ultraviolet region of the spectrum to 12.6 percent in the near infrared region, and 10.7 percent for visible light. This value matches that for soil somewhat lighter in color than that typical of the lunar maria, on the average, but close to ground determinations of the albedo for Mare Fecunditatis.

Observers repeatedly offered contradictory evaluations of the soil color, ranging from greenish to brownish. This can be explained by the fact that because of the observed uniqueness of the reflecting and scattering properties of the lunar soil at sight angles close to the normal there is a greenish hue. An increase in sight angle results in the appearance of a red-brown hue. The difference in color perception increases with increase in the angle of incidence of light on the surface of the soil. It is prcbable that the visual impression of particular hues occurs because there are greenish, as well as brownish, grains of glasses and minerals in the soil.

Microscopic study separated a number of different types from among the particles of lunar soil, some of which differ significantly from earth formations. Two main sets can be distinguished: particles of primary magmatic rocks (basalt types); and particles that have been subjected to definite trans- /7 formations on the lunar surface. Characteristic of the former is the persuasively fresh appearance observed on earth in freshly crushed samples of permanent rocks. They show virtually no traces of roundness and are angular in shape.



Lunar soil will sustain a sheer wall, forming steep natural slopes.

There are, on the other hand, a great many sintered particles of apparently complex shape, often vitrified on the surface, as well as a definite number of spherical fused formations, solidified spherules of glass and metal appearance similar to the "space beads" found on earth.

The following groups of particles have been separated from the larger fractions and are under investigation.

Basaltic rocks. Two types, characterizing the conditions of solidification of the basaltic fusion, can be distinguished among these rocks: fine-grained basalts; and coarse-crystal basalts of the gabbro type. They comprise almost one-fourth of all coarse-grain fractions. The basic materials are plagioclases, pyroxenes, ilmenite, and olivine. The relative content of each varies greatly in the different sections.

Feldspathic rocks (anorthosite). White, polycrystalline grains, in sm amounts. They are of interest because the researchers consider them to be representatives of lunar bedrock scattered over considerable distances.

Grains of individual minerals. Identified among the monomineral grains thus far are plagioclase, olivine, pyroxene, and ilmenite, that is, the basic minerals of basaltic rocks. There are not many of them in the large fractions, but their number increases with decrease in particle size.

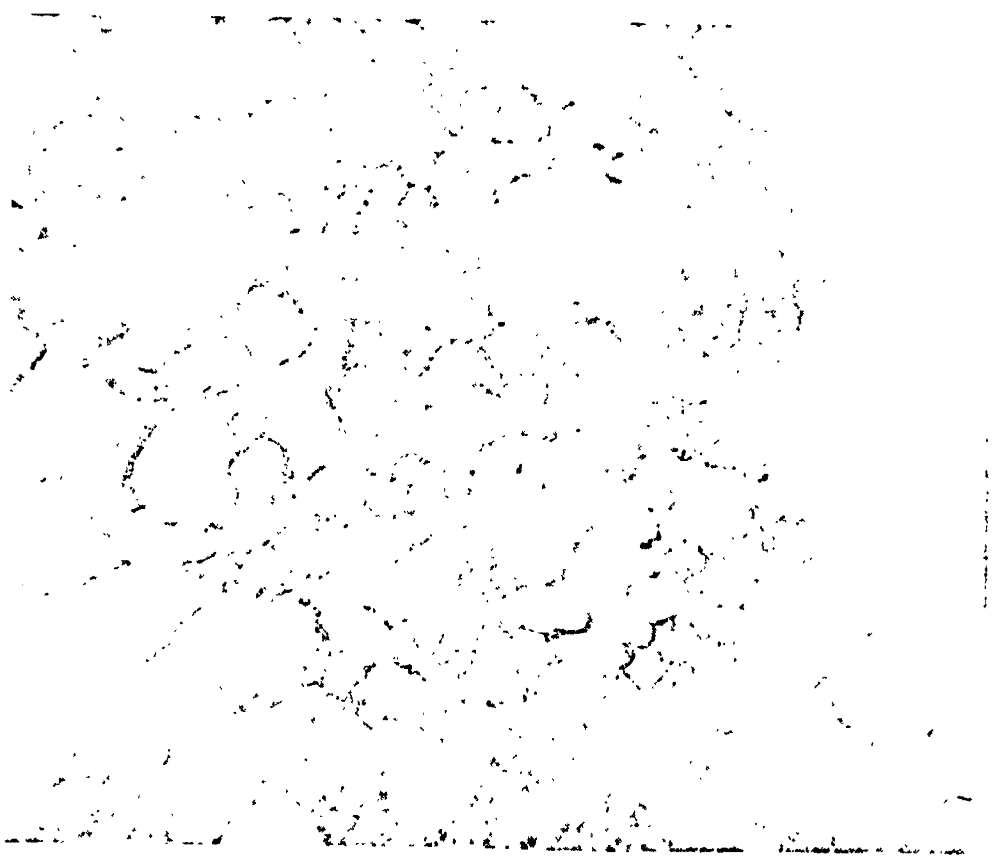
Solidified spherules and beads and similar formations. Glass beads, and pear-shaped and dumbbell-shaped solidified spherules of different colors are found. They are transparent, cloudy white, greenish, yellow brown, and opaque, often hollow. Their sheens range from glassy to metallic. The number of these formation increase in the small fractions. They form at temperatures greatly in excess of the melting point of the rocks and meteorites from which they spattered in the molten state.

Breccias. Cemented, lithified rocks formed as a result of the consolidation of finely crushed regolith material and containing, in various proportions, all of its components, including particles of primary magmatic rocks. Rounded particles are noted for some of the breccias, as is loose consolidation, resulting in ready mechanical destruction of these particles. A characteristic feature of many breccias is magnetizability. Breccias comprise up to 40 percent of the total number of particles.

Sinters. Small sintered particles forming aggregates with a very complex, irregular, branching shape. Like the breccias, they include all types of particles, all of the regolith components. Sinters comprise 15 to 20 percent of the total number of particles. Practically, they are found only in the large fractions. /8

Breccias and sinters are of interest as an index of how the particle consolidation process takes place on the lunar surface simultaneously with the rock grinding and crushing processes.

It should be emphasized that the fact of some cohesion of lunar soil had been known prior to this time. But the fact of the complex shape of the soil particles, while included among the reasons, evidently was underestimated. It would appear that the purely mechanical bonding of the grains, lending to the formation of individual lump-like aggregates, can be explained in particular by the features of particle shape and the specifics of particle surfaces.



Coarse-grained portion of lower zone of lunar soil core. In the center is a solidified glass spherule of natural origin.

Principal types of lunar regolith particles. Magnified.

Glasses' vitrified and scorified particles. Over half of all types of lunar soil particles were fused or scorified to some degree on one, or several sides. The color of the glass formed depends on the composition of the fused particles. Predominant is glass ranging from dark brown to black. Bead, slag-like fusion, as well as smooth, glazed vitrification, is found.

This typically lunar fusion can occur only during the instantaneous heating of a particle that is cold throughout, and it is this that draws a sharp distinction between this sort of vitrification and volcanic glasses, for example.

Glass of volcanic origin (volcanic ash) resembles one type of brownish, large-bead grains, fused all the way through, with the characteristic conchoidal fracture that could form during crushing of comparatively large masses of fused rock. The total quantity of glasses of this type is small.

It should be pointed out that the content of the different morphological types of particles varies with core depth. Some decrease in the relative content of sinters and scorified particles, and an increase in the number of particles of basalts of the gabbro type, are noted with depth. The latter can be indicative of the composition of the primary rocks in the landing area.

Chemical Composition of Lunar Rocks

	Basaltic Rock Luna 16	Fine Fraction Luna 16	Basaltic Rock Apollo 12	Fine Fraction Apollo 12
SiO_2	43,8	41,7	40	42
TiO_2	4,9	3,39	3,7	3,1
Al_2O_3	13,65	15,32	11,2	14
FeO	19,35	16,8	21,3	17
MgO	7,05	8,73	11,7	12
CaO	10,4	12,2	10,7	10
Na_2O	0,33	0,37	0.45	0.40
K_2O	0,15	0,10	0,065	0.18
MnO	0,2	0,21	0,26	0,25
Cr_2O_3	0,28	0,31	0,55	0,41
ZrO_2	0,04	0,015	0,023	0,09

/9

Particles of metallic iron. These particles are found from time to time in the form of individual fragments, evidently iron meteorites, as well as in the form of small inclusions in breccias and sinters. They determine the basic magnetic properties of lunar regolith.

Mechanical, electromagnetic, and thermal and physical properties of the soil are under study. Transmission of heat through the layer of lunar material under space vacuum conditions, for example, is by radiation and contact heat conduction. Measurements have revealed that soil specific heat does not depend on the density of the covering, but is, on the average, that of earth rocks, and that the heat conduction has extremely low values, considerably lower than those for the best of the earth's heat insulating materials.

The chemical composition of different soil fractions is now under study. The soil material, in its chemical composition, is crushed basaltic type rock. We indicated the basaltic nature of the surface rocks on the moon as far back as 1966, using Luna 10 data.

The table lists some of the data on the composition of a fine fraction, and of pieces of compact rock, obtained by Luna 16, and presents comparative data for the Apollo 12 samples. Some tendency toward a reduction in the content of a number of elements, FeO, TiO_2, and others, in the fine fraction as compared with the compact rock, can be observed. There is a definite increase in others in the fine fraction, particularly Al_2O_3, Th, U, and others. The content of Th and U is of the same order of magnitude as it is in the case of the Apollo 12 and Apollo 11 samples. while Th is of the order of 10^{-4}, and U is of the order of 10^{-5} percent. Despite the fact that the intake site for Luna 16 was 900 km from the Apollo 11 intake site, in Mare Tranquillitatis, they differ considerably from the latter in lower contents of TiO_2, ZrO_2 rare earth elements, and certain others, and in a higher FeO content. It is interesting that the Luna 16 and Apollo 11 samples have identically high contents of such space-produced inert gases as He, Ne, Ar, Xe, and Kr in the fine fractions, as compared with the Apollo 12 samples. At the same time, as will be seen from the table, in overall composition, the Luna 16 samples are very similar to the Apollo 12 rock samples obtained in Oceanus Procellarum some 2500 km from the Luna 16 landing site. The quantity of regolith in the Oceanus Procellarum area evidently is slight.

As of this time we have established the presence of 70 chemical elements in the Luna 16 samples and have made isotopic determinations. Short-lived radionuclides, formed by the solar wind, are present in the soil material.

Thus, the crystalline rocks on the surface of the lunar maria are of the same basaltic type, but differ in content of certain chemical elements. Their composition approaches the composition of primitive basalts on earth.

The lunar maria are plains once filled with volcanic lava. The basalt type rocks form as the most readily melted part during zone melting of the planet's internal material. It may be assumed that the overall course of the differentiation of the material of the Earth and of the Moon, and, probably, of other planets of the earth type, followed similar paths, although reaching different stages of development.

The material of these lava maria has been subjected to lunar crushing, and perhaps it can be said even to "lunar weathering." Weathering, the destruction of rocks on earth, takes place primarily as a result of the effects of carbon dioxide, water, and organisms. None of these are present on the moon. The factors acting to destroy rocks on the moon are completely different, including as they do the solar wind, corpuscular cosmic radiation, meteorite impacts, significant variations in the temperature on the surface, and space vacuum. The problem is to decide which single factor, or factors, are paramount in the processes involved in the disintegration of surface lunar rocks.

Meteorites and micrometeorites, which can strike the moon at tremendous velocities, could destroy a tremendous mass of lunar surface rocks, mixing up the whole of the loose material. But it is necessary to find sufficient signs of these meteorities in the lunar soil. There is no doubt that corpuscular radiation acts on lunar rocks, for there is induced radioactivity, and the like. But deep penetration into the rock is lacking. Finally, it may be that volcanic eruptions on the moon, in the space vacuum, cause the processes of grinding and the formation of ash-like material. This still is only conjecture, also in need of proof.

Study of lunar rocks is particularly important to an understanding of the processes that took place on earth during the period of its early existence.

All of this is work for the future.

Translated for National Aeronautics and Space Administration under contract number NASw-2038 by Translation Consultants, Ltd., 944 S. Wakefield Street, Arlington, Virginia 22204.